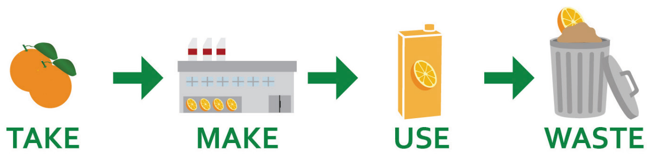
The Value of Circularity in Sustainable Food Systems

The circular economy, or circularity of a system, is an intentional effort to design out waste and pollution, keep products and materials in use and regenerate natural systems. Waste reduction and food loss recovery via the utilisation of coproducts and by-products from other industrial processes has long been a component of the animal feed and pet food supply chain. As the animal food industry considers its role in climate neutrality and other sustainability outcomes, existing processes, as well as new technologies and innovations, are being explored.

In this article, we address the role a circularity metric could have in assessing and valuing sustainability efforts for the animal food supply chain and consider measurement and assessment limitations that exist, which restrict the industry's potential to accurately account for its environmental impact and role in a circular economy.

Defining Circularity

In the most basic sense, the transition toward a circular economy aims to close the loop on existing linear systems such that produced materials stay in use, waste and pollution are designed out and the regeneration of natural resources is pursued. A pure linear system follows a path of take-make-use-waste;[1] whereas a circular system is a cycle of make-use-reuse-recycle-recover.



A pure linear system follows a path of take-make-use-waste. In this example, oranges are made into orange juice and the resulting citrus pulp is discarded.

Idealistically, circular systems could operate where waste no longer exists, material loops are closed, and products are recycled indefinitely, but in reality, materials degrade over time and some quantity of new materials and energy must be injected into any circular material loop to overcome these losses.[2]

A circular economy, or circularity, can be contemplated at multiple levels of scale across all industry sectors. While numerous definitions exist, Kirchherr *et al.*[3] propose the definition:

"Circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations."

As food and agricultural systems evolved in the last 100 years to the scale that currently allows us to feed 7.9 billion people, it generally evolved linearly with input dependencies, resource degradation (e.g., soil organic matter depletion) and environmental pressures generation.[1] Increasing the scope of circularity into existing linear food and agricultural systems is paramount to our ability to achieve the desired outcome to sustainably feed the United Nations predicted population of 9.7 billion by 2050, while further reducing and enhancing agriculture's impact on the environment. The linkage between circular economy and sustainable development is not generally noted in circular economy definitions; however, circular economy transitioning should parallel ongoing sustainability efforts.[4]

Food and agriculture consists of a complex system of systems. Identifying components to map and transition toward a circular economy within food and agricultural systems depends on where you draw a boundary and consider scale. Here, the animal food sector circularity is considered, and in particular, the role of coproduct and by-products. Scale is variable, but could ultimately be national, across a region or livestock type, or at a corporate level.

Coproducts from arable product processing, which are not consumed by people as food or drink or used to produce biofuels or other industrial products, as well as by-products, generally rendered from inedible animal protein, recovered fats and oils, or waste materials, are important ingredient sources for the animal feed and pet food industry. Using these products, the animal feed and animal protein sector contribute to the circular economy.[5]

Waste reduction and food loss recovery via the utilisation of coproducts and by-products from other industrial processes have long been a component of the livestock feed and pet food supply chain. As the industry considers its role in climate neutrality and other sustainability outcomes, existing processes as well as new technologies and innovations are being explored.

Example Circular Components in Feed Production

There are many examples in the feed industry where using coproducts or by-products allows the industry to further 'close a cycle' toward circularity. Although these materials are intentionally produced, the potential for animal feed use increases the value and sustainability of the production process.

For example, rapeseed and sunflower production's primary product is vegetable oil. The remaining coproducts, rapeseed and sunflower meals, concentrated in protein content, are used in feed production. Sugar extracted from sugar beets result in residual sugar beet pulp, which is an excellent ruminant feed. Molasses, for which no human consumption market can be found, is often diverted to feed manufacturing. Citrus pulp left over after juice fruit extraction is another example of a material that represents a significant biophysical share of the original raw material where animal feed provides a solution.

A circular system follows a make-use-reuse-recycle-recover cycle. In this example, oranges are made into orange juice, the resulting citrus pulp is fed to dairy cows, and the resulting organic matter becomes fresh fertilizer for the orange grove.

There are also examples of by-products where the materials destined for feed represent a smaller biophysical share compared to the main product, usually destined for human consumption. Wheat bran remains from bread production and brewers' grains, and yeasts are left over from beer production. Many people are unaware of the by-products resulting from palm oil production that have a useful purpose in animal nutrition, namely palm kernel meal and palm fatty acid distillates.

There are also examples in the slaughtering process of animal carcasses. Because of dietary preferences, a proportion of nutritious and safe animal protein is not destined for human consumption. In meat production, the processed animal protein resulting from the rendering process is a highly digestible protein source, which is very suitable for animal nutrition. In fish processing sites, trimmings remain, which are suitable for carnivorous fish species raised in aquaculture.

Another important diversion to animal food is surplus food, which is sometimes referred to as "former foodstuffs." These are foodstuffs clearly intended for human consumption, but due to a production error are no longer considered suitable. Examples include bread, cookies, breakfast cereals and confectionery. The use of these materials in feed is the most direct contribution of feed production to food waste prevention, as these products obtained a food status and are not downgraded to waste, thanks to their feed use.

Due to the use of food-grade ingredients in this case, former foodstuffs represent a source of high-quality nutrients that in principle are not affordable for the feed production sector. Often these processed former foodstuffs can be found on the feed market as bread meal or cookie meal. The former foodstuff processing sector is increasingly able to source materials beyond their traditional suppliers.

Coproduct and By-product Environmental Benefits
'Embracing' livestock sector circularity potential has been highlighted in platforms of significance, such as the 2021 United Nations Food Systems Summit. The environmental benefits of coproduct and by-product use can be considered from multiple perspectives, each offering insights into the product use impact, though none singularly provide complete insight into the potential value. When used as feed and pet food, coproducts and by-products offer landfill avoidance, material upcycling, reduced environmental footprint, minimised food waste and water recovery. However, while the benefit concepts are identified, benefit quantification is limited. The following offers examples of quantified environmental benefits.

Ondarza and Tricarico[6] recently assessed methane emissions from human-inedible, coproduct and by-product feeds based on product type and use within U.S. dairy cattle rations. Accounting for both enteric and manure-based methane production, by-product and coproduct use generated significantly lower emissions than if the material had instead gone to a landfill, 68 versus 3,448 CO_2-equivalent, g/kg product dry matter. A similar quantification can be made across the U.S. feed supply chain. Each year, U.S. domestic livestock consume 258 million tonnes of feed and approximately 40 percent of those ingredients are upcycled from other industries.[7] Because of its use as animal feed, 103 million tonnes are diverted from the landfill and 61 million tonnes of CO_2-eq loss are avoided.

Rendering is the cooking and drying of meat and/or other animal by-products not used for human consumption in order to recover fats and protein. There are 28.1 million tonnes of materials that can be rendered and produced annually in the U.S. and Canada; without rendering, that volume is sufficient to fill all U.S. landfills in four years.[8] In the process of upcycling renderable materials, Gooding[9] estimated that the average facility directly emits 20,000 tonnes of CO_2 through internal operations and indirectly emits 4,000 tonnes of CO_2 via their electrical utility. However, the CO_2 emitted through the total direct and indirect emissions is still only 30 percent of the emissions that would result from material decomposition in landfills. Water is also recovered, treated and returned to the environment during rendering. The North American Renderers Association estimates 3.7 billion gallons of clean water are reclaimed and returned to rivers, lakes and streams annually.

The above examples illustrate that for the initial owner of coproducts and by-products, the feed and pet food outlet is more sustainable than alternative disposal options. For a feed manufacturer, the use of coproducts and by-products also offer a more sustainable choice when compared to alternative, land-requiring arable sources. Data from the European Former Foodstuff Processors Association (EFFPA) estimates that the use of 3.5 million tonnes of processed former foodstuffs in European countries is equal to over 400.000 hectares of corn, thereby reducing the pressure feed demand puts on arable land. And those processed former foodstuffs have nutritional qualities that make them a good alternative feed ingredient to arable sources such as corn, wheat or barley.

A study by Giromini *et al.*[10]determined that processed former foodstuffs can be considered a "fat-fortified version of common cereal grains" thanks to the generally higher fat content while being comparable in starch content. From a biochemical point of view, lipids contain carbon and hydrogen in a more reduced state compared with other nutrients (e.g., carbohydrates and proteins). The better potential for oxidisation therefore provides a greater energy yield. Given the proven difficulties in handling fats.

and mixing them with other ingredients for the formulation of complete feeds, former foodstuffs represent a valuable processing advantage in compound feed production given that the lipids are already part of the matrix. The previously heat-treated (or cooked) starch can be speculated to be of relatively high digestibility quality, which is of particular interest due to the limited capacity of piglets to digest raw starch.

While the aforementioned data points to the environmental benefit potential of coproduct and by-product use, the data set is limited. As the value of circular economy in food and agricultural systems gains prominence, the quantification of outcomes and impacts must expand.

Potential Circular Economy Metrics

The circularity of a system is ultimately defined by how completely the loop can be closed. And while it can be helpful to assess the circularity of each input singularly (i.e., flow of a particular material within the system), ultimately all inputs and losses must be considered collectively. Therefore, energy or water requirements needed to upcycle a coproduct or by-product, as well as carbon or nitrogen loss following animal consumption, are as important to assessing the circular economy as tracking the flow of the materials within the system.

Circular economy can be used as a benchmark to measure progress on a scale ranging from linear at one end to perfectly circular at the other. Therefore, we could ask: what is the current degree of circularity and how far could we realistically move toward perfect circularity within any food system? With this as a measure, a ratio (α) of total recovered material to total material demand could be performed where perfect circularity equals one.[2]

Unfortunately, material "upcycling" (i.e., transforming unwanted by-product into a higher quality or higher valued item) is generally only possible with the addition of energy to the system; therefore, additional questions and metrics should be considered. How much energy is needed to upcycle or restore the material to the desired product, and how does the required energy needed for upcycling compare to obtaining the desired equivalent from a virgin source?[2] Cullen proposes, calculating energy considerations (β) as one minus the ratio of energy required to recover or upcycle material (e.g., coproduct or by-product) to energy required to create an equivalent input from a virgin source, where, again, the resulting value equals one for perfect circularity. For animal feed coproduct and by-product use, this could mean quantifying energy for the virgin-sourced material based on nutritional equivalents from other sources or raw commodities.

Proponents of circular economy do not always consider the energy input needed to sustain circularity, but the benefit of material handling should not be considered without addressing the impact in conjunction with energy. Therefore, cojoining the two means a circularity index could be quantified by multiplying α and β, again where perfect circularity equals one.[2]

Two other circularity metric considerations include: 1) identifying the number of times a resource is used in a product system along with longevity, the length of time a resource is used, as an indicator of resource efficiency in the circular economy. Where the higher the number the indicators show, the higher the contribution to circularity.[11] And 2) accounting for a combination of material mass flow and product utilisation rate, where the greater the material recirculation and higher the utilisation rate of a product, the better the circularity.

Assessing circular economy within food and agricultural systems is challenging because both material and energy flows must be coupled with production, processing, distribution and consumption.[1] The Ellen MacArthur Foundation[12] revised methodology for circularity indicators includes considerations for biological based materials, and it acknowledges the challenge associated with 'material loss' when typical downstream product recovery (e.g., the recovery of plastic for continued reuse) is not possible in agricultural systems. This complexity inherent to food and agricultural systems deserves additional focus and standardisation to accurately assess their value and benefits.

Market Recognition and Acceptance of Circularity's Value

Circularity in feed production has clear sustainability merit. It allows for a different kind of resource use, while contributing to food production. In the animal production value chain, the circularity of feed, i.e., the use of coproducts and by-products, deserves to be a key indicator of sustainable feed production.

Increasingly, there are production specifications laid down by upstream value chain partners that could restrict feed producers from optimising circularity in feed formulation. A product specification that surfaces and is often part of a claim on the animal product labelling, is the demand for plant-based animal feed. In Europe, market development for animal protein produced with plant-based feed has increased with the reapproval of certain processed animal proteins as feedstuffs. In Europe, former foodstuffs, where often animal by-products, such as milk, eggs or honey, are constituents, are then also excluded. In the U.S., examples have arisen where products labelled as natural beef require vegan-based animal feed sources, thus preventing use of the key coproduct, whey, from milk processing.

The by-products resulting from palm oil production are sometimes even specifically targeted. Due to the negative perception of palm oil, feed manufacturers are sometimes asked to exclude all 'palm oil products' from the feed formulation, although it can hardly be argued that the feed use of palm kernel meal or palm fatty acid distillates are a factor of importance for palm tree expansion.

At the same time, food manufacturers themselves are suppliers to the feed industry through the supply of former foodstuffs. In this position as supplier, it is important that a circular economy mentality is adopted. Selling resources to the feed sector should never be seen as a disposal route, but very much the placing on the market of so-called "secondary raw materials."

Future Opportunities for Circularity in Animal Feed and Pet Food

Circularity will continue to evolve as an indicator within the broader sustainability discussion. Relative to the biologic, interconnected and complex nature of food and agricultural systems, advancing our ability to measure and assess those systems' circularity is paramount to gaining sustainability benefits of a circular economy. The use of coproducts and by-products in feed and pet food is just one component of circularity opportunities in food and agricultural systems. As the feed and pet food industry strives to offer and communicate benefits and solutions available to the animal and pet food consumers, the industry must be able to accurately reflect economic and environmental opportunities available through greater circularity. This is important in demonstrating reduced environmental impact as well as need to access and use of currently available 'waste' from other industries. Due to the potential scope and scale of system boundaries, the industry would benefit from methodologies capable of assessing the circularity of complex food and agricultural systems. As a methodology for complex biological systems becomes standardised and normalised by use, feedstuff circularity could become commonplace, thereby providing feed manufacturers with a clear incentive to maximise the content of 'circular feed' in their formulations.

REFERENCES

1. Basso, B., Jones, J., Antle, J., Martinez-Feria, R., Verma, B. Enabling circularity in grain production systems with novel technologies. Agricultural Systems. 193, 103244 (2021)
2. Cullen, J. Circular Economy – theoretical benchmark or perpetual motion machine. Journal of Industrial Ecology. 21 (3) 483-486 (2017)
3. Kirchherr, J., Reike, D., Hekkert, M. Conceptualizing the Circular Economy: an analysis of 114 definitions. Resources, Conservation & Recycling 127, 221-232 (2017).
4. Pauliuk, S. Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. Resources, Conservation & Recycling 129, 81-92 (2018)
5. European Feed Manufacturer's Federation. Resource efficiency champions: co-products, an essential part of animal nutrition. https://fefac.eu/wp-content/uploads/2020/07/05362_co-products_brochure_003.pdf (2019)
6. de Ondarza, M.B., Tricarico, J.M. Nutritional contributions and non-CO_2 greenhouse gas emissions from human-inedible byproduct feeds consumed by dairy cows in the United States. Journal of Cleaner Production 315, 128125 (2021).
7. Institute for Feed Education and Research. Animal feed/food consumption and COVID-19 impact analysis. Prepared by Decision Innovation Solutions. http://ifeeder.org/wp-content/uploads/210301-FINAL-REPORT-IFEEDER-Animal-Feed-Food-Consumption-COVID-19.pdf (2020)
8. Wilkinson, A.D. and Meeker, D.L. How agriculture rendering supports sustainability and assists livestock's ability to contribute more than just food. Animal Frontiers 11(2) 24-34 (2021).
9. Gooding, C.H. Data for the carbon footprinting of rendering operations. Journal of Industrial Ecology. 16(2) 223-230 (2012).
10. Giromini, C., Ottoboni, M., Tretola, M., Marchis, D., Gottardo, D., Caparulo, V. Nutritional evaluation of former food products (ex-food) intended for pig nutrition. Food Additives and Contaminants: Part A. 34(8) pp. 1436-1445 (2017).
11. Figge, F., Thorpe, A.S., Givry, P, Canning, L., Franklin-Johnson, E. Longevity and circularity as indicators of eco-efficient resource use in the circular economy. Ecological Economics. 150, 297-306 (2018).
12. Ellen MacArthor Foundaton Circularity Indicators: An approach to measuring circularity. https://ellenmacarthurfoundation.org/material-circularity-indicator (2019)

Lara Moody

Lara Moody is the executive director for the Institute for Feed Education and Research (IFEEDER), where she provides visionary leadership to the U.S.-based public charity's activities, including program development, strategic partnerships and collaborative resourcing. Most recently, she has been working to promote awareness of IFEEDER's Sustainability Road Map project, which will help the U.S. animal food industry lower its environmental footprint and advance industry solutions to the global climate change challenge.

Email: lmoody@afia.org

Anton van den Brink

Anton van den Brink is the senior policy and communication manager for the European Compound Feed & Premixes Association (FEFAC), where he is engaged on sustainability-related topics connected to European compound feed manufacturing, such as responsible soy sourcing, environmental foot printing, circular economy, nutrient efficiency and food waste. He played a leading role developing FEFAC's Feed Sustainability Charter 2030 and revised Soy Sourcing Guidelines. Van den Brink also serves as executive director of the European Former Foodstuff Processors Association.

Email: avandenbrink@fefac.eu